Cortical Control of Neural Prostheses

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Work Performed During the Reporting Period

Our main push in this reporting period is to get a monkey to directly control a robotic arm. In ongoing research, however, we have continued recording from previously implanted arrays in monkey M, and added arrays and an implantable microdrive in monkey L. Both animals continued working on the direct brain-control virtual reality (VR) task and on direct brain-control of the robotic arm. We completed dissections of monkeys H and K, allowing us to determine the localization of previous implants, and started the process of more detailed histological analysis. We also implanted several of our neurotrophic electrode arrays in rats and have seen physiological evidence for growth of neurites into the electrodes.

Surgeries

We performed two implants in monkey L in this period. The first implant was our standard implant composed of microwire arrays. In the second hemisphere of this animal, we implanted a microdrive with 64 microwires. The microwire arrays are presently producing data. The microdrive showed promise in the first few days. Seven of the eight shuttles (each of which had 8 wires) had activity within the first week after implant. However, the implant site developed an infection, which we treated with systemic and topical application of antibiotics. Since resolution of the infection, we have not seen any activity on any of the wires in the microdrive.

VR Control, single units

Our work on the direct control of a cursor in virtual reality is progressing. We have one animal now (monkey M) focused on the VR tasks. To date, the animal has learned to control

the movement of the cursor using a population vector mapping between brain activity and cursor movement, both with its arms free to move, and with its arms restrained. We have also extended this paradigm, so that the animal is now learning to control movement of the cursor from limited sets of neurons. Depending on the relationships between neuronal discharge and arm movement in 3-dimensional space, we place from one to three dimensions of cursor movement under brain control, with movement of the cursor in each dimension controlled by the activity of a single neuron. Control in this paradigm is not as good as in the population vector mapping, but the animal has learned to reliably move the cursor into all of the targets. This is a strong indication to us that the ability to simultaneously record enormous numbers of neurons may not be a crucial element in developing a viable neuroprosthetic system for controlling a device such as a prosthetic arm.

Robot control

Our problem continues to be making a stimulus-response association in which the animals learn that they are controlling the robotic arm. We ran monkeys M and L extensively on the auto-shaping paradigm, and while we saw evidence that the animals were in fact slowly learning to control the device (steadily decreasing time intervals between rewards), we never saw evidence that they were aware of this control (sudden drops in time intervals, or subjectively assessed attentional engagement with the task). Therefore, we have changed paradigms, and are now developing other means to get the animals to actively control the robotic arm. The first option that we are considering is to have the animals apply some force directly to the robot, and over time, translate the neuronal activity associated with that force directly into movement of the robot. Another option we are considering is to train the animals

first in a tele-robotics task, where they can use arm movements to direct the robot to achieve goals that the monkey's own arms cannot reach.

Neurotrophic implants

We have built and implanted three neurotrophic arrays in rats. Each array consisted of 4 neurotrophic electrodes, each with differing concentrations of neurotrophic agent (NGF). The design thus provided internal controls for each of the implant concentrations. In this initial implant session, we found several elements of our design that were less than optimal, and have made adjustments for future implants (for example, because of the diameter of the polyimide tubing used to contain the neurotrophic gel, we realized that we need to sharpen the tips of the implants). Nonetheless, physiological recording over the course of several weeks has provided clear evidence of growth into the tips of the electrodes – each of the electrodes with neural growth factor began recording action potentials with signal-to-noise ratios on the order of 10 to 20. This is in contrast to our usual recordings with simple insulated microwires, which in our hands typically result in signal-to-noise ratios for the action potentials on the order of 2 to 5.

Localization of previous implants

A combination of intra-cortical microstimulation techniques and receptive field mapping studies provided us with initial ideas of the location of the microwire arrays that we were recording from in monkeys H and L. Dissection of the recording sites has by and large verified those impressions. In monkey H, we had implanted microwire arrays in several areas of sensorimotor cortex, two in somatosensory cortex (areas 2 and 5), and two in motor cortex. In monkey K, key recordings were taken from two implants that were clearly in somatosensory

cortex, one on the anterior crown of the central sulcus into area 4, and one further anterior, probably in area 6.

Work Anticipated During the Next Reporting Period

In the next recording period, we will continue recording the from the active implants. We will be focused on writing up our results from two separate experiments: first, we will begin writing one manuscript showing the ability of various ensemble activity -> velocity mappings to reconstruct arm trajectories. Our other manuscript will describe the ability of the animals to control the cursor in VR using direct brain control. We also will continue training monkey M on the VR task, looking at his ability to control the cursor under various ensemble activity -> velocity mappings. We will also be working with monkey L to establish the link that allows him to directly control motion of the robotic arm from brain signals.